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Powertrain NVH Development
Geartrain NVH

Since geartrain noise of modern diesel engines has become a dominant noise source, FEV has developed an analytical method for the analysis of geartrain dynamics aimed at identifying and optimizing potential noise sources. This simulation method is an essential tool that fits into the development process of a technical product. It requires minimal effort to set up the model in combination with less calculation time. Several industrial projects have shown, that with the help of such a simulation - even at an early design stage - a geartrain can be optimized.

Geartrain Model

Engine geartrain noise is caused by tooth impacts due to torque fluctuations. Intermitting combustion, irregular torque demand of the auxiliaries (i.e. injection system), and torsional vibrations of the crankshaft causes these torque fluctuations. The simulation of the geartrain dynamics is based on a combination of Multi-Body System Simulation (MSS) and Finite Element Analysis (FEA) - see Figure 1. To consider the whole body movement, an MSS model is used. The flexibility of the crankshaft and camshaft is considered by FEA models, which are implemented into the MSS model. The strongly nonlinear dynamics in the tooth contact, as a main influence parameter of gear noise concerns, are described by a '3-Phase Force Element', which is an MSS module developed at FEV.

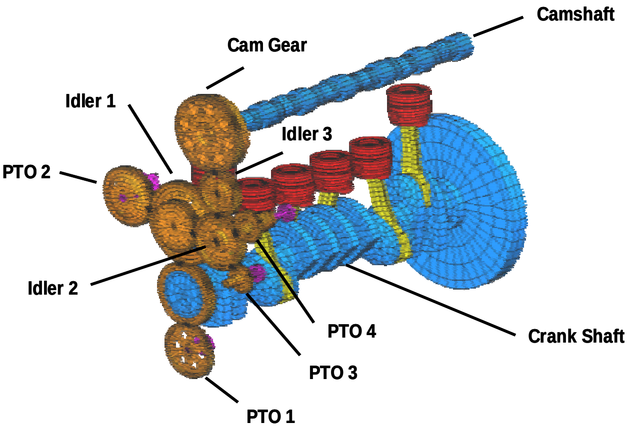

Figure 1 FEA Model

Geartrain Dynamic Analysis

In a first step, the present state analysis is performed to establish the geartrain's weak points. Based on these results an optimization process is carried out. Several modifications are investigated and assessed to achieve an optimum result. The investigation starts with a speed sweep calculation to investigate the dynamic behavior of the geartrain in the entire speed range of the engine. Thus, critical engine orders or resonance frequencies can be identified (Figure 2).

With the help of an analytical modal analysis, the corresponding mode shapes can be obtained. This gives a hint as to which components are involved. Two general types of mode shapes can be identified in a geartrain; the first one includes many gears, whereas a second one is limited to a single component. Any countermeasure has to account for these differences. If many gears are involved, the gear drive has to be changed entirely, e.g. by changing the position of auxiliary gears. If a single component shows high amplitudes, it is sufficient to modify this component only.

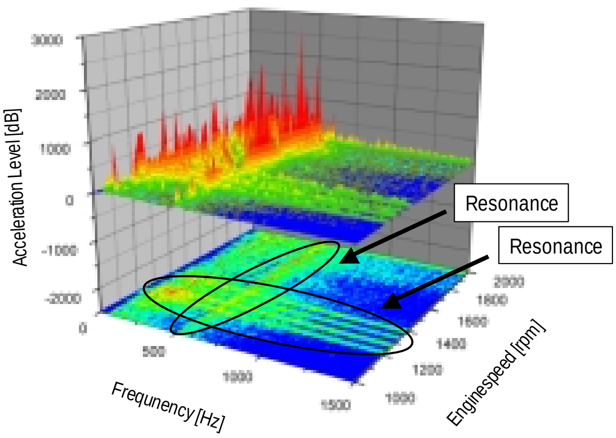

Figure 2 Speed Sweep

Optimization

The optimization process itself focuses on critical parts identified in the present state analysis. In principle, there are several possibilities to optimize a geartrain:

- Modified Gear Positioning
- Modified Phasing
- Mass Variation of Gears
- Mechanical Pre-Load System/Scissor Gear
- Viscous Damper
- Changed Number of Teeth
- Modified Engagement Factor / Helix Angle
- Modified Backlash

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A sensitivity analysis indicates the most promising and effective solutions. For example, often it can be recognized that the variation of tooth backlash has little influence on the dynamics of the gear. Contrary to that the change of the position of an accessory gear or a higher load on an accessory gear can improve the dynamic behavior of a gear train significantly. One example for an optimization is given in Figure 3.

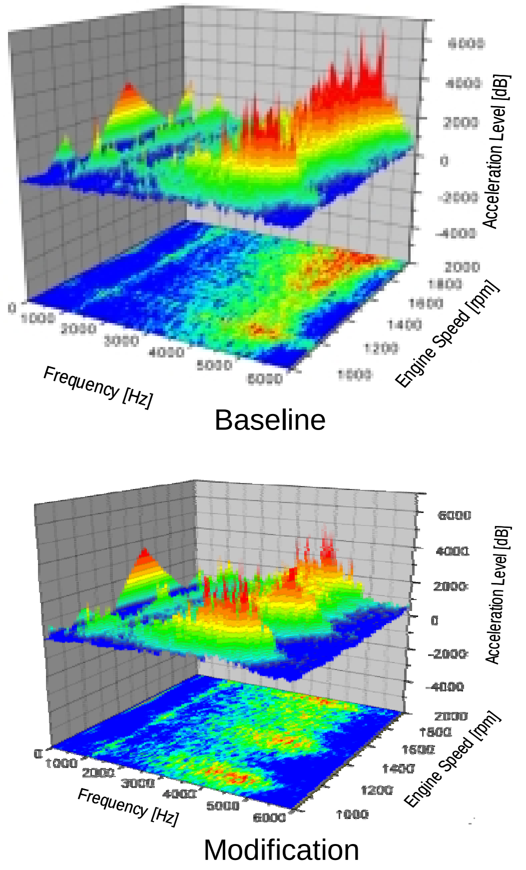

Figure 3 Dynamic Behavior of a PTO

In this case, a load variation was implemented on a PTO. The significant reduction of the peaks in the resonance area is obvious.

To obtain another clear evaluation parameter, an overall level for each gear acceleration is used. This value is the integration of the acceleration over frequency and engine speed weighted by the moment of inertia of the gear. This value is given in dB. This is an energy parameter comparable to the surface velocity level.

Practice has shown that an optimum result can only be achieved by combining several modifications. To get an overview of the best combination, the overall acceleration level is used (Figure 4). Thereby the influence of the countermeasures on the whole geartrain can be assessed very clearly. In this case, a significant reduction of the acceleration level of each gear can be recognized.

Summary

The described method has proven to be an efficient tool for optimizing geartrains at an early design phase. Weaknesses can be found in the present state analysis. By

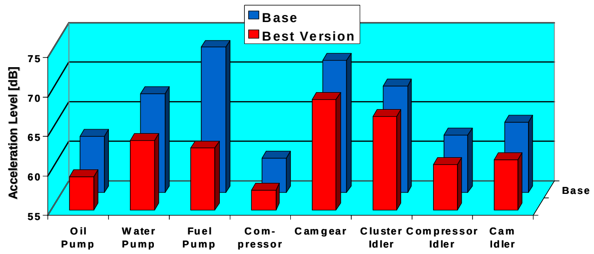

Figure 4 Integral Acceleration Levels

means of a sensitivity analysis, useful parameters for the optimization of the geartrain can be detected. By recalculation of the modified model, countermeasures can be designed and assessed. The efficiency of such countermeasures and their influence on the rest of the geartrain can be evaluated.

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